SUPERNOVA REMNANTS AND THE CARBON ABUNDANCE IN M33

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ABSTRACT

We have combined IUE and optical spectral data on a supernova remnant in M33 in order to determine the abundance of carbon in the interstellar gas of M33. We have used new shock model calculations to guide the interpretation and find that a substantially lower value of the ratio C/O than has been assumed previously for M33 may be necessary to explain the data. However, some inconsistencies in the observed and predicted line intensities indicate that the spectra may be partly contaminated by H II region emission or that the preshock gas has been ionized by nearby stars.

INTRODUCTION

Recent improvements in the techniques for calculating shock wave models (Raymond 1979, Shull and McKee 1979, Dopita et al. 1984) have allowed observations of the emission line ratios from supernova remnants (SNRs) to be interpreted in terms of abundances. For all SNRs larger than roughly 5 pc diameter, the supernova blast wave will have swept up many times more interstellar gas than was ejected by the supernova. Hence, this analysis can be used to determine abundances in the interstellar gas. This has been done optically for SNRs in several nearby galaxies, including M31 and M33 (Dopita, D'Odorico and Benvenuti 1980; Blair, Kirshner and Chevalier 1982; Dopita et al. 1984; Blair and Kirshner 1984), with the results from SNRs being compared with results from H II regions to assess the gas phase abundance gradients in these galaxies. One of the uncertainties in the abundance gradient analyses is the unknown abundance of carbon, which has no readily detectable lines in the optical. Previous investigations have had to assume a value for the C/O ratio. Since carbon is an important coolant in both photoionized and shock heated gas, an incorrect carbon abundance can affect the line intensities (and hence abundance estimates) of other elements.

Observations of galactic SNRs with IUE (e.g. Benvenuti et al. 1980; Raymond et al. 1981) have shown that the ultraviolet emission lines of carbon are among the strongest lines in SNR spectra over a wide range of conditions. In addition, the ratio C III] λ1909 / C IV λ1550 is sensitive to shock velocity. During the fifth and sixth years of IUE, we have observed five SNRs in M33 in order to investigate the carbon abundance and determine to what extent the previously assumed abundance of this element may have affected abundance estimates for other elements. Here we will discuss only the observations of M33-8 from the catalog of D'Odorico, Dopita and Benvenuti (1980). In collaboration with S. D'Odorico, P. Benvenuti and M. Dopita, we obtained an 840 minute SWP exposure during an ESA-US1 shift pair. This remnant was chosen for its high surface brightness and low reddening. The remnant has a diameter of about 11 pc and appears to be an isolated emission region on interference filter photo-

TABLE 1

Comparison of M33-8 Observations to Model Calculations

Line	λ	M33-8 F(λ)	M33-8 I(λ)	Model A 90 km/s	Model B 120 km/s
Si IV	1394	}	}	52	25
O IV]	1402	<64	<80	57	245
C IV	1550	336	411	346	547
He II	1640	<46	<56	28	24
O III]	1664	163	197	219	196
Si III]	1892	<40	<50	103	60
C III]	1909	57	70	402	176
[O II]	3727	(520)[a]	543	604	542
[Ne III]	3869	(26)[a]	27	23	17
[S II]	4070	(14)[a]	14.4	21	19
[O III]	4363	(12.5)[a]	12.8	32	27
He II	4686	(12)[a]	12.1	5	4
Hβ	4861	100	100	100	100
[O III]	4959,5007	340	338	413	343
[N I]	5200	<4	<4	23	26
He I	5876	10.3:	10.0:	4	4
[O I]	6300,6364	27:	26:	45	55
Hα	6563	315	300	303	297
[N II]	6548,6584	152	144	153	151
[S II]	6717,6731	197	187	228	225
[O II]	7320,7330	<5	<4.7	39	26
E(B-V)		0.05		---	---
F(Hβ)		1.26 E-14		---	---

[a] Line intensities in parentheses from Dopita et al. (1980).

TABLE 2

Model Parameters and Abundances Relative to Cosmic

Parameter	Model A	Model B	Cosmic Abundances[a]
n_o (cm^{-3})	5	2	---
V_s^o (km s^{-1})	90	120	---
log He	10.93	10.93	10.93
log C	7.70	8.00	8.52
log N	7.56	7.56	7.96
log O	8.42	8.62	8.82
log Ne	7.22	7.52	7.92
log Mg	6.92	7.22	7.42
log Si	6.62	7.22	7.52
log S	7.00	6.90	7.20
C/O	0.19	0.24	0.50

[a] Cosmic abundances by number, from Allen (1973).

graphs.

The observed and reddening corrected line fluxes are listed in Table 1, along with optical data from Dopita et al. (1980; data in parentheses) and Blair and Kirshner (1984). The optical reddening estimates and Hβ flux from Blair and Kirshner (1984) are also shown. Reddening correction has been performed assuming a theoretical ratio of $I(H\alpha)/I(H\beta) = 3.0$ and the extinction curve of Seaton (1979). We note that the comparison of the optical and UV line intensities is only as good as the optical flux calibration (± 35%; Blair and Kirshner 1984).

INTERPRETATION

Qualitatively, the low value of the C III] / C IV line ratio argues for a high shock velocity, and the small C III] / O III] λ1664 ratio implies a C/O ratio considerably smaller than the value of 1/3 previously assumed (Dopita et al. 1980). Table 1 shows two model spectra for shock velocities of 90 and 120 km/s. Preshock densities of 5 and 2 cm^{-3} were assumed to match the densities inferred from the optical [S II] doublet ratio, and the preshock gas was taken to be fully ionized. The models were computed with an updated version of the code used by Raymond (1979) with improved excitation, ionization and recombination rates. The abundance sets used are listed in Table 2. While the agreement between observed and predicted intensities of the strong optical lines is good, and could clearly be improved by modest adjustments to the assumed abundances, two major discrepancies stand out. The C IV/C III] ratio predicted by the 90 km/s shock is far too low to match the observation. The 120 km/s shock does better, though a still higher velocity would be needed to reach the observed value. However, the upper limit on the O IV]-Si IV blend at 1400 Å conflicts with model velocities above 90 km/s. This cannot be avoided by increasing the C to O abundance ratio because of the high observed value of the O III]/C III] intensity ratio. The only apparent way to reconcile the models with the observed spectrum is to appeal to ionization of the preshock gas. The ionization potential of O III coincides with that of He II, while the C III ionization potential is 7 eV lower. Model stellar atmospheres have very deep He II absorption edges, so that the oxygen in an H II region is mostly O III, while the carbon is largely C IV. A slow shock (V_s < 90 km/s) in gas in which the carbon is preionized to C IV would produce the observed large C IV/C III] ratio without producing too much emission at 1400 Å. It might also be possible for radiation produced by the SNR itself to create the necessary ionization state if He II absorbs most of the photons above the O III edge, but this would require a specific evolutionary state for the SNR.

While the strong [S II] doublet suggests a basically collisionally ionized gas, the temperature sensitive line ratios [O II] λλ7320,30/λ3727 and [O III] λ4363/λ5007 are much lower than predicted by the models. While higher velocity shock models do produce lower values for these ratios, the strong upper limit on O IV] λ1400 precludes a high enough shock velocity for this to be a viable explanation. On the other hand, low values of these ratios are typical of photoionized gas. While there is no clear evidence for H II region contamination for this SNR, another M33 emission region has recently been identified as just such a combination: a small diameter SNR embedded in an

H II region (M33-7, see Blair and Kirshner 1984). One could imagine either contamination of the spectrum by H II region emission or photoionization of the shocked gas of the SNR by nearby stars. The observed ratio of the [S II] λ4070/λλ6717,30 lines is close to that predicted by the shock models, suggesting that the [S II] is indeed formed by collisionally ionized gas. Presumably this means that the [S II] emission of the photoionized regions is weak, as is generally observed. One would expect that the lines of [O I], [N I] and He II would also be produced in shocked gas. Their weakness relative to the Balmer lines (when compared with the shock models) suggests roughly equal contributions of shocks and photoionized gas to the Balmer line intensities.

With the exception of the 1400 Å feature, model B does a reasonable job of matching many of the strong emission line intensities. As can be seen from Table 2, the C/O ratio for this model is about half of the cosmic value, while the C III]/O III] line intensity ratio from Table 1 is larger than observed by roughly a factor of 2.5. Hence, it is conceivable that the C/O ratio in M33 has been previously overestimated by a factor of three to five, although a more complete analysis is needed to establish this conclusively. This is large enough to affect the abundance determinations from SNR spectra (cf. Dopita et al. 1984).

SNRs in nearby galaxies are difficult targets for IUE and the uncertainty in the relative calibration of optical and UV data places limitations on the effectiveness of the comparison. The increased sensitivity and resolution of the Faint Object Spectrograph on Space Telescope (Giacconi 1982; Table 1) along with simultaneous UV/optical coverage (1150-7000 Å) will permit many of the M33 SNRs to be observed and will allow a more complete abundance analysis to be performed. This work is supported by NASA grant NAG 5-87 to the Smithsonian Astrophysical Observatory.

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